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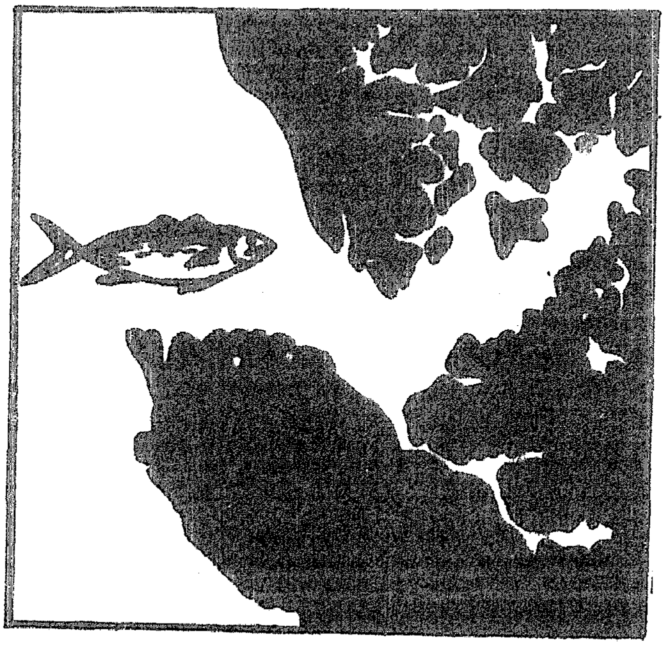

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REPORT ON

THE PHYSICAL, BACTERIOLOGICAL & BIOCHEMICAL ANALYSES OF SEAWATER SAMPLES COLLECTED OFF EXISTING SEWAGE OUTFALLS IN THE SIERRA LEONE RIVER ESTUARY

prepared by

THE INSTITUTE OF MARINE BIOLOGY & OCEANOGRAPHY

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May, 1980.

PREFACE

The studies reported here were undertaken as part of a wider environmental feasibility study for the establishment of a modern sewage system in Freetown. In aim of this part of the study was to determine whether the hydrological regime of the Sierra Leone River estuary would permit the large-scale introduction of sewage into the estuary without damaging the environment. The important factors were whether

(1) there would be sufficient dilution of the sewage
(2) fleatable particles or other substances would create significant adverse effects in the estuarine ecosystem.

Our results would suggest that at certain points where local circulations occur it would be inadvisable to locate untreated sewage outfalls. Such points are frequently observed in small embayments.

These studies have been of short duration but the data would serve as baseline for more extended investigations which would give a more complete picture of the seasonal patterns in the estuary.

D.E.B. Chaytor
Director

TABLE OF CONTENTS

1. INTRODUCTION

The Sierra Leone River Estuary is a tidal estuary of the semi-mixed type with the saline oceanic water entering it on a diurnal cycle. Most of it is shallow except for a deep channel which passes close to the Freetown shoreline.

The climate of Sierra Leone is marked by a very distinct change between a very wet rainy season and a dry season. The rainfall pattern comprises the conventional thunderstorm rains of the early and late wet season, mainly related to disturbance lines moving from east to west across the country, and the steady monsoonal rains of the main wet season, roughly from mid-June to late September, moving into the country from the south-west off the Equatorial Atlantic.

The volume of fresh water entering the Estuary is large during the rainy season and greatly reduced during the dry season. Consequently there is a marked fall in salinity during the rainy season and higher salinities prevail during the dry season. The tidal range of the Estuary (spring: 3.03m; neap: 2.28m) does not impede normal use of the Freetown harbour. The tidal variations can be felt as far as 42 miles inland along the water courses of the Sierra Leone River and its tributaries.

The nature of the shores and bottom, the hydrography and chemistry of the estuarine system in relation to the prevailing climatic conditions have been reviewed by Findlay in 1978 (see appendix for review paper).

The City of Freetown is largely unsewered. There are many short sewer lines which discharge directly into the Estuary. Nearly all of them have a sea-wall discharge point with the exception of the Kingtom outfall which is submarine and the Queen Elizabeth II Quay collecting system which discharges close to the shoreline at Cline Point. All the sewer discharge untreated sewage and with the exception of that at Government Wharf the volume of discharge is relatively small.

Along the northern shore of the Freetown Peninsula are located some of the major industries as well as the Queen Elizabeth II Quay which is at the eastern extremity of the harbour. The industries include the Kissy Oil Refinery Terminal, the Sierra Fishing Company also at Kissy, the Wellington Distilleries and Brewery. All of them discharge raw or partially treated waste waters directly into the Estuary.

The proposal to construct a sewerage system for Freetown and Greater Freetown has necessitated a study of the existing chemical and bacteriological conditions of the water and sediments in the vicinity of the sewage outfalls at Murray Town, Kingtom, Government Wharf and Cline Point (Fig. 1.).

Water samples were collected from the outfall sites for the following chemical analyses - Dissolved oxygen content, biological oxygen demand and the concentrations of chloride, nitrate, nitrite, phosphate and ammonium. Other analyses made were for total suspended solids and total and faecal coliforms.

2. DESCRIPTION OF OUTFALL SITES

The locations of the four (4) outfall sites along the shores of the Sierra Leone River Estuary are shown in Fig. 1. The Shores along the Freetown mainland are mainly of lateritic headlands projecting into the Estuary. These headlands alternate with bays where the nature of the soil (either clay or an agglomerate of sand and pebbles) appear to be weak to resist marine erosion. Numerous streams which show a clear seasonal fluctuation in their discharge drain the Freetown Peninsula into the bays.

The positions of the outfalls investigated with respect to their location on the headlands and bays on the northern shore of the Freetown Peninsula are shown in Fig. 2. Outfall No.1 is situated immediately west of Cline Point which is a lateritic headland. The effluent pipe

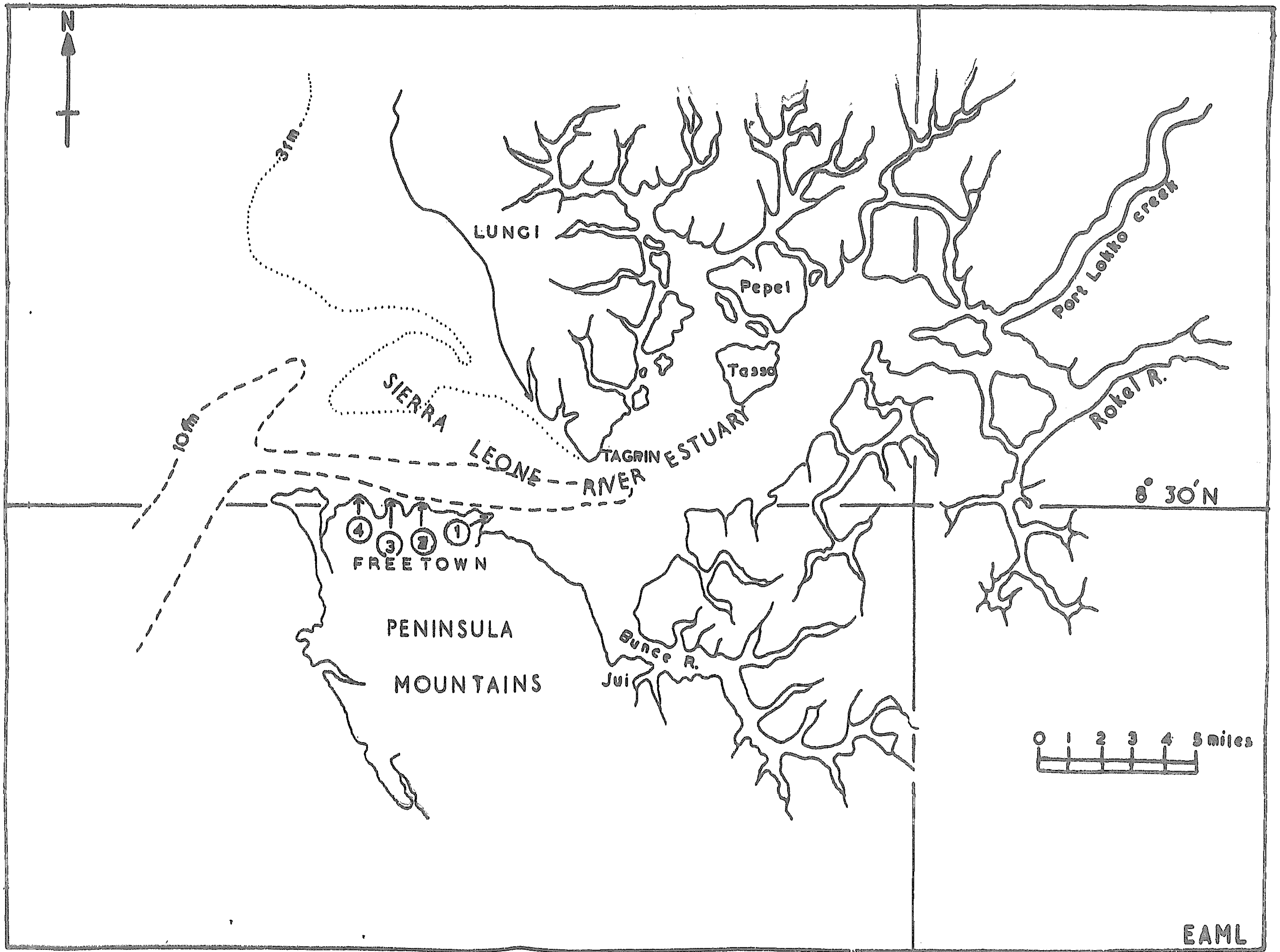


Fig I. Location of outfalls along the Sierra Leone River estuary

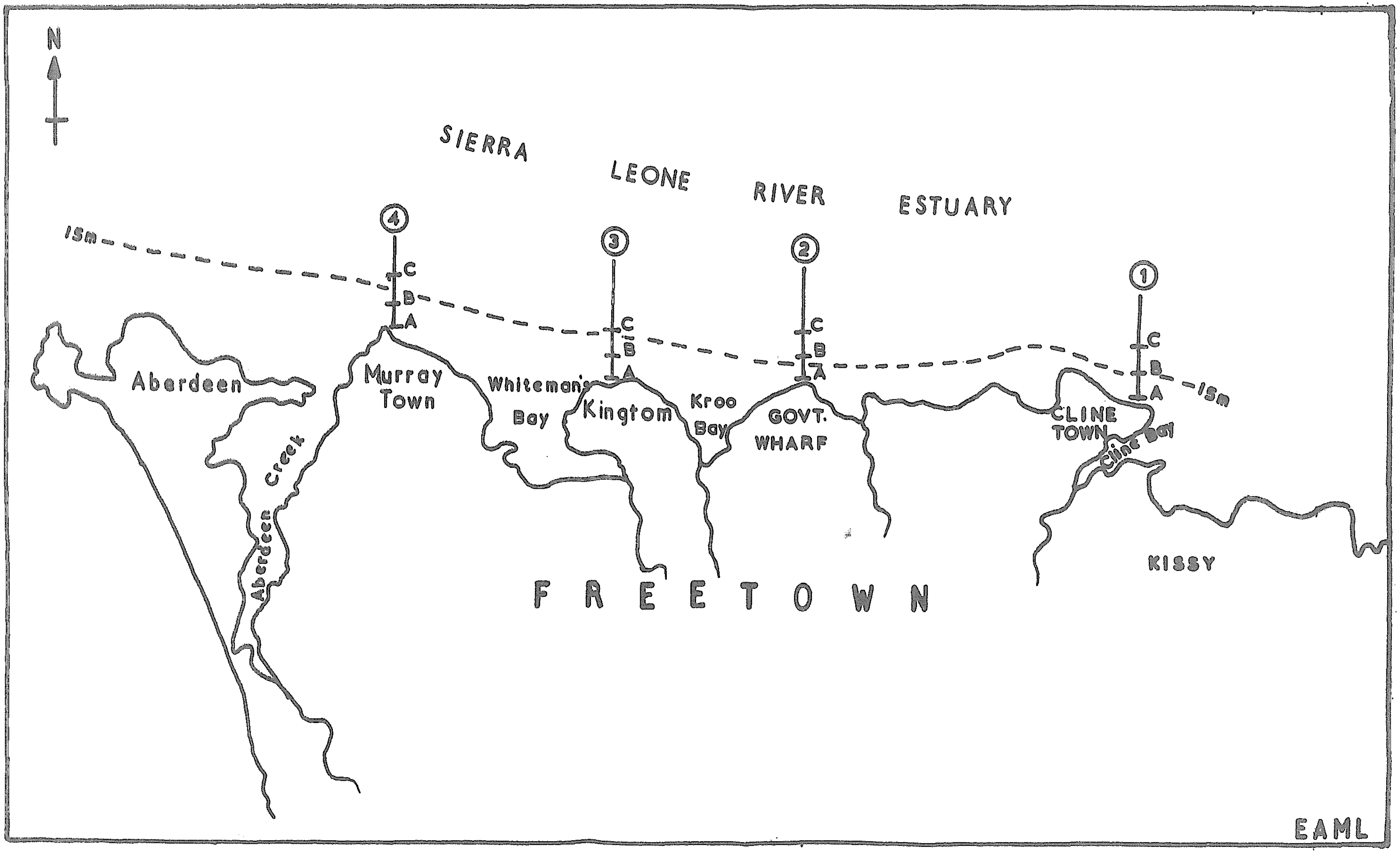


Fig 2. Location of outfalls and sampling stations along the Freetown mainland

stands about 0.5m above high water mark at neap tide among rocks of gabbro which were deposited there during the construction of the Queen Elizabeth II Quay. The movement of currents at this site appears to be upstream when the tide is running out (that is at low tide) and upstream again at high tide. This indicates that the outfall is in a sheltered location where the exchange of water between that trapped in the Queen Elizabeth II Quay and the main estuary water is very small. Intense mixing of these two bodies of water appears to take place about 0.2km upstream immediately opposite the Cline Point headland. The depth of the water at approximately 10m offshore from the outfall varies from about 0.5m at low tide to 2.0m at high water neaps. It gradually increases to about 20m approximately 100m away from the outfall site. The deep channel of the Estuary (Fig.1) with a depth varying between 25 and 30m lies approximately 250m north of the outfall site.

Outfall No.2 at Government Wharf stands about 1.5m above surface water at high water neaps. The sewage effluent pipe is about 2.0m underneath the floor of Pier No. 1. This pier is about 0.2km west of the Falcon Bridge headland which is also lateritic but contains some outcrops of gabbro that extend 10 to 20m into the estuary water. Immediately west of the pier is Kroo Bay. The area is greatly affected by water coming from Kroo Bay especially at low tide. The quality of this water appears to be extremely poor being heavily loaded with debris and detritus, and a lot of plastics, piassava and empty tin cans. Very little or no mixing appears to take place between the bay water and the estuary water except in the area immediately opposite the Falcon Bridge headland. Front-lines separating the bay water from the main estuary water are clearly visible on the water surface around the area. Floating tin cans, bamboo, pieces of sticks and detritus clearly demarcate the front-lines. Usually, the bay water is pale brown or yellow and murky while the estuary water is green or blue. These front-lines migrate inshore and offshore depending on the state of the tide. At low tide, the bay water extends to about 50 to 100m offshore but at high tide this zone reduces to about 5 to 10m from the shore at the outfall site. The depth of the water 10m from the outfall varies from about 2.5m at low tide to about 5m at high tide neaps. This increases to about 8 to 11m and 14 to 17m at 50 and 100m offshore respectively.

The shore of the Kingtom Peninsula, the northern end of which outfall No. 3 is located (Fig.2), is composed mainly of sand with outcrops of gabbro and laterite that extend 5 to 10m into the estuary water. The sewage effluent pipe, leading from a septic tank on the shore, dips and extends about 3m into the estuary water. The outfall lies in a sheltered area to the east of which is a smaller headland on which the Sierra Leone Electricity Power Station is sited. The nature of the currents affecting this area appear to be extremely complex since the Peninsula lies between Kroo Bay on the east and Whiteman's Bay on the West (Fig.2). The exchange of water between the two bays in probably more pronounced than between the bay water and the estuary water. Clearly visible front-lines indicate where bay waters separate from estuary water. At low tide, the movement of water is more in an upstream direction with anti-clockwise circulation within the bays. Some amount of exchange of water between the two bays seems to take place during this state of the tide. The reverse trend however appears to take place at high tide when the circulation of water in the bays is more or less clockwise with little or no exchange. It is suggested that the area in which No.3 outfall is sited is a "dead spot", with hardly any movement of water during high tide. The depth of the water at this outfall varies from 2.5m about

10m offshore and about 9 to 11m and 15 to 17m at 50m and 100m offshore respectively.

Outfall No.4 is sited east of the Murray Town headland which is mainly composed of gabbro. It stands about 3m above surface water at high water neaps. Mixing of the water at this site appears to be more intense at low tide than at high tide. At high tide however, the water passing this point flows into Whiteman's Bay (Fig.2). Frontlines, quite common at outfalls 2 and 3, are less evident here - probably a consequence of the intense mixing which takes place at the mouth of the Estuary. The depth of the water at this site varies from about 2.5m onshore to about 17 to 19m approximately 100m offshore from the outfall.

3. SAMPLING STATIONS AND SAMPLING REGIME

Sea water samples for chemical analysis were collected from the four (4) outfall sites at various tidal regimes using an inflatable rubber dinghy powered by a 40 HP outboard engine. Cruises, which lasted for about 5 to 6 hrs were arranged such that on a sampling date if outfalls No.1 or 4 was sampled at high tide the intermediate outfalls were subsequently sampled serially until No.4 or 1 was eventually sampled at low tide.

Two fixed stations (B and C) were sited 50m and 100m offshore at each outfall site (Fig. 2). The "A" stations were fixed on every occasion according to the state of the tide, being 5m offshore at high tide or 10m at low tide. The samples for chemical analyses were taken at each hydrographic station from the surface and bottom and at mid-water, except at the "A" stations where the depth of the water did not warrant the collection of mid-water samples. The depth of the water at each station varied according to the state of the tide. It never exceeded 5.0m at any of the "A" stations. At the "B" and "C" stations, the depth ranged from 6 to 20m and 14 to 20m respectively. Mid-water samples were then collected after recording the depth of the water.

Water temperature and salinity observations during sampling were carried out using an MC.5 Temperature/Salinity Bridge manufactured by the National Institute of Oceanography, Great Britain. Observations on the two factors were made at each station at the surface and at 1.0m depth intervals until the bottom was struck. Changes in the water with reference to current velocity and direction, occurrence of front-lines, and water quality were routinely observed and recorded.

All sea water samples for chemical determinations were taken using a Van Don sampler with a holding capacity of approximately 10l. Surface water samples were taken at 0.5m depth. Afterwards, the sampler, weighted with a 4.0kg metal piece of iron, was then dropped to the bottom and the depth of the water noted. Bottom water samples were then taken 1m above the bottom. The depth recorded was then halved, after which mid-water samples were then taken.

Water samples for dissolved oxygen and B O D determinations were taken from the Van Don sampler before drawing water for any other analyses. Care was taken to avoid contamination of the sample with outside air by introducing the water into 250ml B O D bottles by means of a rubber tube touching the bottom and flushed three times. Each sample for dissolved oxygen determination was immediately treated with 1.0ml manganese sulphate and 1.0ml of a mixed reagent of potassium iodide and sodium hydroxide and kept in an insulated ice box.

Sea water samples for the determination of chloride, nitrate, nitrite, phosphate and ammonium concentrations were stored in 1l plastic bottles and kept in a cool place.

Samples for total and feacal coliform counts were collected in 250ml glass stoppered bottles and kept in the insulated ice box. Again, water samples for the determination of heavy metal concentrations were stored in glass stoppered bottles and kept in a cool place onboard.

Bottom mud samples were taken with a Van Essen grab sampler having an holding capacity of 2l. Samples so collected were stored in about 4l capacity plastic packets.

4. METHODS OF ANALYSIS

Temperature - Salinity - was determined using a salinity and temperature measuring bridge, type MC.5 designed by the National Institute of Oceanography, U.K. With this instrument *in situ* measurements can be made.

Dissolved oxygen - A modification of the classical Winkler procedure as described by Strickland and Parsons (1968) was used routinely. Duplicate tests were fixed in the field and 100ml. titrated as soon as possible on return to the laboratory.

Chloride - was determined from salinity measurements with the MC.5 bridge or from determinations of salinity by the microtitration method of Kalle (1951).

Nitrate - Nitrogen - The determination is based on Strickland & Parson's (1968) combination of the methods of Grasshoff (1964) and Wood *et al.* (1967). In it , about 95% of the nitrate is reduced to nitrite by passing the sample after treatment with an ammonium chloride buffer, through a column containing cadmium - copper filings. The nitrite is then determined by the method of Bendschneider & Robinson (1952).

Nitrite - nitrogen - The determination is based on Shinn's (1941) modification of the classical Greiss - Ilosvay method as adapted for sea water analysis by Bendschneider & Robinson (1952).

Ammonia - nitrogen - The determination is based on the modified Koroleff method (1969) in which ammonia reacts with sodium hypochlorite and phenol in an alkaline medium in the presence of catalytic amounts of sodium nitroprusside to give indophenol blue, an intensely coloured compound. Sodium citrate is added to prevent the precipitation of magnesium hydroxide from the sea water (Solorzano, 1969).

Phosphate - phosphorus - The determination is based on the modified single solution method of Murphy & Riley (1962) in which the sample is treated with an acidic reagent containing molybdate, ascorbic acid and antimony III.

Total Suspended Solids - Replicate samples of water are filtered through a Whatman No.2 filter paper and the retained dried matter is determined by weighing.

Total Coliform - The determination is based on the MPN method using a modified formate lactose glutamate medium as recommended by PHLS Standing Committee on the bacteriological examination of water supplies (1969).

Faecal Coliform - The determination is made using brilliant green lactose bile broth. The methods for total and faecal coliforms determination are described in Report No.71; The bacteriological examination of water supplies; published by HMSO, London for the Department of Health & Social Security (1969).

5. RESULTS

Bacteriological

The probable number of total and faecal coliforms for the various outfall stations are given in Table 1A & B. Faecal coliforms were found in every sample taken. The numbers were usually greater in the bottom layers than in the surface layers and also nearer the point of discharge than away from them except at Outfall No.2 stations. Gross pollution from coliforms was found at the Government Wharf outfall and

TABLE 1A

Total Coliforms per 100ml

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	22/4	110		8	25		
	5/5	80	80				
	13/5	350	350	50	140	110	95
2							
	22/4	1800+			35		
	5/5	1800+	1600				
	7/5			550		1800+	6
	13/5	1800+	1800+		1800+		
3							
	29/4	35	110	250	350	170	80
4							
	7/5	900	1600	550	350	350	20

TABLE 1B

Faecal Coliforms per 100ml

OUTFALL	Date	Station A Surface	Station A Bottom	Station B Surface	Station B Bottom	Station C Surface	Station C Bottom
1	22/4	17		2	2		
	5/5	17	80				
	13/5	170	130	17	70	35	70
2							
	22/4	1800+			35		
	5/5	1800+	1600				
	7/5			170		900	4
	13/5	1800+	1800+		1800+		
3							
	29/4	5	7	14	80	14	50
4							
	7/5	350	1600	250	170	110	7

TABLE 2

Salinity, ‰

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	33.78	34.7	33.19	33.19		
	22/4	33.42	33.54	33.35	34.25		
	25/4	34.65	34.65	34.35	34.55		
	7/5	32.75	32.85	32.40	32.90		
	13/5	29.2	29.2	29.2	29.2	29.00	29.00
2							
	22/4	34.65	34.75	34.75	34.75		
	25/4	34.25		34.85			
	29/4	33.35	33.4	33.00	33.4	33.5	
	7/5	33.2	33.4	33.15	33.65	33.1	33.6
	13/5	30.9	31.0	30.2	30.7	30.0	30.5
3							
	22/4	34.8		34.7	35.2		
	29/4	33.56	33.57	33.55	33.56	33.56	33.56
	7/5	33.15	33.6	33.0	33.45	33.05	33.65
	13/5	31.0	31.0	30.7	30.9	30.5	30.7
4							
	22/4	34.49	35.15				
	29/4	33.56	35.55	33.57	33.55	33.51	
	7/5	33.1	33.2	33.3	33.55	33.45	33.65
	13/5	30.5	30.5	30.6	30.6	30.6	30.6

TABLE 3

Temperature ^{o}C

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	27.21		27.25	27.00		
	22/4	29.8	29.4	29.8	29.00		
	25/4	28.8	28.8	29.2	29.00		
	7/5	29.8	29.8	30.2	29.00		
	13/5	30.0	30.0	30.0	30.0	30.4	30.2
2							
	22/4	29.00	28.6	28.5	28.2		
	25/4	28.8		28.4	28.8	28.4	28.4
	29/4	29.0	28.6	28.8	28.6	29.0	
	7/5	29.4	28.9	29.4	28.8	29.4	28.8
	13/5	30.00	29.6	29.8	29.6	29.8	29.6
3							
	22/4	29.0		29.0	28.6		
	29/4	28.2	28.2	28.2	28.2	28.2	28.1
	7/5	29.5	29.0	29.8	28.7	29.2	28.7
	13/5	29.8	29.7	29.8	29.5	29.6	29.5
4							
	22/4	29.4	28.0				
	29/4	28.2	28.25	28.2	28.2	28.2	
	7/5	29.0	28.78	28.9	28.8	28.9	28.8
	13/5	29.4	29.4	29.4	29.2	29.4	29.2

slightly so at the Murray Town Outfall at all states of the tide. Pollution was not heavy at the other two outfalls - probably a consequence of their design and discharge characteristics.

Chemical

Salinity and temperature of the estuary water were high throughout the period of investigation (Table 2 & 3). By mid-May salinity dropped slightly due to the dilution of the estuary water by run-off from the land - a consequence of the first squalls which mark the start of the rainy season. The chloride content (Table 4) is related to the salinity and there is no evidence of sewage contributing to its concentration.

The dissolved oxygen concentration (Table 5) is high at all depths at all states of the tide. Only on a few occasions was undersaturation observed. This feature of the estuary water has also been recorded by Watts (1958) and Leigh (1973).

The biochemical oxygen demand of the estuary water indicates that it is of fairly good quality (Table 6). It is probable that at the point of discharge (the shoreline which is rocky) the liquid part of the sewage rapidly becomes diluted and dispersed whereas the solid part becomes held in suspension in the tidal currents which flow into the nearby bays where they become broken up and dispersed. The low concentration of total suspended solids (Table 7) appears to support the idea of rapid dilution and dispersal of the sewage.

The data for nitrate - nitrogen, nitrite - nitrogen, ammonia - nitrogen and phosphate - phosphorus are given in Tables 8-11.

The nitrate - nitrogen and nitrite - nitrogen values were high at Outfall No.2 than at any of the others. At Outfall No.2 it decreased as one moved away from the shore and also with depth. At the other

TABLE 4

Chloride Content °/oo at 25°C

OUTFALL STATIONS

OUTFALL	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
1	18/4	19.12	19.65	18.78	18.78		
	22/4	18.91	18.98	18.87	19.39		
	25/4	19.62	19.62	19.45	19.57		
	7/5	18.52	18.58	18.32	18.61		
	13/5	16.47	16.47	16.47	16.47	13.36	16.36
2							
	22/4	19.62	19.68	19.68	19.68		
	25/4	19.39		19.74			
	29/4	18.87	18.89	18.67	18.89	18.96	
	7/5	18.78	18.89	18.75	19.04	18.72	19.01
	13/5	17.45	17.51	17.05	17.34	16.93	17.22
3							
	22/4	19.71		19.65	19.94		
	29/4	18.99	18.99	18.99	18.99	18.99	18.99
	5/5	18.75	18.93	18.67	19.01	18.69	19.04
	13/5	17.51	17.51	17.34	17.45	17.22	17.34
4							
	22/4	19.53	19.91				
	29/4	18.99	20.15	18.99	18.99	18.96	
	7/5	18.72	18.78	18.84	18.99	18.93	19.04
	13/5	17.22	17.22	17.22	17.28	17.28	17.28

TABLE 5

Dissolved Oxygen % saturation

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	127.67	132.04	121.68	113.52		
	22/4	150.99		147.82	69.74		
	25/4	122.33		141.31	140.77		
	7/5	157.29		152.20			
	13/5	116.55	114.32	100.98	112.09	133.11	116.96
2							
	22/4	138.70		131.02	134.89		
	25/4	104.15		103.73	126.31	126.31	135.26
	29/4	133.32	141.36				
	7/5	124.89	142.12	143.11	139.91	136.32	96.91
	13/5	90.52	132.81	98.97	107.89	130.29	128.06
3							
	22/4	136.51		136.63	136.14		
	25/4	129.45	130.56	131.67	127.24	131.67	135.94
	7/5	129.74	135.62	143.67	110.32	146.89	135.14
	13/5	121.97	98.43	108.13	107.73	101.11	133.21
4							
	22/4	107.71	100.13				
	29/4	138.30	135.68	137.23	136.69	137.17	
	7/5	151.07	138.15	101.54	137.61	136.49	109.47
	13/5	116.19	134.15	110.64	89.19	126.49	132.80

TABLE 6

Biochemical Oxygen Demand (mg/1)

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	3.19	2.34	1.57	10.48		
	22/4	3.22		1.47			
	25/4	1.61		0.96	2.62		
	5/5	1.24	1.29	0.08	0.63	1.39	
	7/5	1.26		0.65			
	9/5	1.91	3.61	0.80	4.94	1.61	2.02
	13/5	1.61	2.22	0.81	1.81	1.41	2.62
2							
	22/4	1.71		0.81	1.41		
	25/4	3.43		0.24	0.71	0.46	0.81
	29/4	1.21	1.41		1.41	11.90	
	5/5	0.87	0.22	0.28	0.65	0.68	1.09
	7/5	1.10	1.11	0.60	0.60	0.81	0.91
	9/5	1.21	0.40	0.40	0.30	0.31	0.81
	13/5	1.62	1.31	0.11	0.91	2.12	2.42
3							
	22/4	0.66		3.62	2.84		
	29/4	0.76	0.91	0.71	0.41	0.66	1.01
	7/5	0.31	0.45	2.22	0.40	1.41	0.40
	9/5	1.11	1.11	1.11	1.41	0.19	
	13/5	0.20	0.44	0.40	0.40	0.30	1.46
4							
	22/4	0.39	0.24				
	29/4	1.11	1.01	0.76	0.91	0.66	
	7/5	1.10	1.26	1.00	0.81	0.66	0.55
	13/5	0.30	1.21	0.55	1.01	0.56	1.16

TABLE 7

Total Suspended Soils (mg/1)

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	1.25	1.00	1.05	0.96		
	22/4	0.68		0.40	0.62		
	25/4	0.52	0.26	0.45	1.75		
	7/5	0.73		1.10			
	13/5	0.31	0.68	0.36	0.84	0.64	0.52
2							
	22/4	0.69		0.68	0.63		
	25/4	0.15		0.49	0.005	0.73	0.45
	29/4	1.395	1.105	0.96	1.25	1.32	
	7/5	0.82	0.70	0.89	0.80	0.58	
	12/5	0.33	0.46	0.29	0.42	0.34	0.37
3							
	22/4	0.61		0.48	0.58		
	29/4	1.23	1.08	1.22	1.38	1.17	1.24
	7/5	0.86	0.76	0.72	0.74	0.69	0.66
	13/9	0.45	0.35	0.29	0.22	0.37	0.31
4							
	22/4	0.55	0.77				
	29/4	1.16		1.20		1.18	
	7/5	0.58	0.66	0.82	0.98		
	13/5	0.25	0.30	0.27	0.27	0.35	0.34

TABLE 8

Nitrate - Nitrogen (mg/1)

OUTFALL	Date	A Surface	A Bottom	B Surface	B Bottom	C Surface	C Bottom
1	18/4	4.7	7.84	1.57	7.84		
	22/4	4.74		1.58	7.20		
	25/4	5.08	5.08	1.69	7.57		
	5/5	6.14	10.23	2.05	9.33	5.12	
	7/5	4.58		1.74			
	9/5	4.77	8.28	4.39	7.26	3.98	4.23
	13/5	4.59	7.54	1.996	7.13	3.96	5.16
2							
	22/4	29.20		8.31	6.79		
	25/4	31.82		8.93	7.29	5.08	3.39
	29/4	29.59	3.36	5.12	6.72		
	5/5	37.78	40.94	6.55	8.39	6.14	4.09
	7/5	29.23	31.28	4.74	6.79	4.74	3.32
	9/5	27.47	30.65	4.77	6.37	5.57	5.57
	13/5	29.30	30.51	4.75	6.75	4.75	3.33
3							
	22/4	7.89		5.31	2.84		
	25/4	7.68	8.41	5.28	3.04	5.12	6.24
	7/5	7.9	8.63	5.47	2.84	5.06	6.32
	9/5	7.96	8.69	5.41	3.02	5.41	
	13/5	7.76	8.71	5.32	3.01	5.16	6.34
4							
	22/4	6.73	5.15				
	29/4	6.81	7.29	6.40	8.00	7.61	
	7/5	6.48	6.95	6.48	7.90	7.58	7.9
	13/5	6.65	7.07	6.34	7.92	7.76	7.92

TABLE 9

Nitrite - Nitrogen (mg/1)

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	0.34	0.02	0.30	0.02		
	22/4	0.39		0.32	0.39		
	25/4	0.44	0.40	0.35	0.48		
	5/5	0.40	0.40	0.31	0.40	0.12	
	7/5	0.40		0.29			
	9/5	0.41	0.42	0.32	0.42	0.13	0.23
	13/5	0.45	0.45	0.35	0.45	0.18	0.33
2							
	22/4	1.32		0.81	0.26		
	25/4	1.57		0.97	0.33	0.04	0.46
	29/4	1.42	1.46	0.84	0.88		
	5/5	1.36	1.46	0.85	0.88	0.04	0.40
	7/5	1.36	1.46	0.81	0.90	0.03	0.40
	9/5	1.19	1.27	0.85	0.89	0.08	0.23
	13/5	1.37	1.42	0.91	0.93	0.14	0.45
3							
	22/4	0.52		0.16	0.02		
	29/4	0.52	0.65	0.15	0.20	0.50	0.60
	7/5	0.52	0.62	0.13	0.21	0.21	0.29
	9/5	0.51	0.58	0.13	0.23	0.23	
	13/5	0.58	0.64	0.21	0.25	0.25	0.35
4							
	22/4	0.24	0.11				
	29/4	0.25	0.45	0.46	0.56	0.40	
	7/5	0.21	0.12	0.48	0.54	0.40	0.40
	13/5	0.25	0.195	0.55	0.595	0.44	0.45

TABLE 10

Ammonia - Nitrogen (mg/1)

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	5/5	0.48	0.96	0.29	1.34		
	7/5	1.64		0.98			
	9/5	0.00	0.07	0.00	0.00	0.00	0.00
	13/5	1.20	1.04	0.80	0.88	0.80	1.36
2							
	29/4	17.61	1.91	3.45	1.72	1.34	
	5/5	0.86	0.96	0.57	1.15	1.44	1.44
	7/5	0.98	0.82	0.98	0.57	0.82	0.00
	9/5	0.00	0.00	0.00	0.00	0.00	0.00
	13/5	10.80	1.20	0.80	1.44	1.20	1.00
3							
	29/4	7.37	1.53	1.91	4.59	3.06	2.20
	7/5	0.82	0.74	0.57	0.57	1.23	2.05
	9/5	0.07	0.00	0.83	0.14	0.42	
	13/5	0.96	0.80	0.72	0.40	0.40	0.40
4							
	29/4	1.63		2.29			
	7/5	0.82	0.41	0.74	0.49	1.80	0.41
	13/5	1.20	0.72	1.12	0.40	0.80	0.32

TABLE 11

Phosphate - Phosphorus (ug-at/1)

OUTFALL		STATIONS					
		A		B		C	
1	Date	Surface	Bottom	Surface	Bottom	Surface	Bottom
	18/4	0.041	0.041	0.204	0.00		
	22/4	0.041		0.082	0.326		
	25/4	0.16	0.4	0.28	0.08		
	5/5	0.157	0.157	0.00	0.434	0.118	
	7/5	0.035		0.035			
	9/5	0.79	0.79		0.95	0.83	0.79
	13/5	1.54	0.98	0.58	0.93	0.62	1.13
2							
	22/4	0.00		0.082	0.245		
	25/4	0.12		0.04	0.04	0.00	0.04
	29/4	0.697	0.375	0.161	0.134	0.027	
	5/5	0.078	0.157	0.667	0.00	0.157	0.039
	7/5	0.035	0.105	0.035	0.035	0.035	0.105
	9/5	0.75	0.99	0.99	0.79	0.99	0.79
	13/5	1.85	1.29	1.08	1.24	1.29	1.34
3							
	22/4	0.082		0.123	0.163		
	29/4	0.857	0.00	0.214	0.214	0.214	0.186
	7/5	0.07	0.14	0.035	0.035	0.00	0.035
	9/5	0.75	0.79	0.79	0.83	0.79	
	13/5	0.62	0.82	0.93	1.13	0.00	0.34
4							
	22/4	0.204	0.367				
	29/4	0.295	0.027	0.107	0.00	0.214	
	7/5	0.07	0.035	0.07	0.07	0.07	0.114
	13/5	0.72	0.67	0.88	0.62	0.31	0.62

outfalls the concentrations were higher in the bottom layers than at the surface. The same trend was observed in the distribution of nitrite - nitrogen at the outfalls.

The concentration of the ammonia - nitrogen in the surface layers of Outfall 2, 3 and 4 stations was greater than in the bottom layers. At Outfall 1 stations the reverse trend was observed. At outfall 1 & 2 stations the highest values were obtained during low water conditions and the lowest values during the change from low water to high water conditions. At Outfall 3 & 4 stations the lowest values were obtained during the change from low water to high water conditions and the highest values under predominantly low water conditions.

The phosphate - phosphorus concentration was high at Outfall 3 stations than at the other stations and appeared to decrease with depth. At the other outfall stations the pattern of distribution was not clearly defined.

The heavy metals appear to be absorbed and concentrated in the bottom muds.

Atomic Absorption Analyses for Heavy Metals

Table 12

A. Water samples (concentration in ppm)

OUTFALL

Stations	Cu	Pb	Zn	Cr	Ni
1B	0.09	2.0	0.14	2.0	6.0
1C	0.05	2.6	2.15	2.0	6.0
2A	0.12	1.3	0.21	3.8	6.0
2B	0.05	2.7	0.14	2.0	5.0
2C	0.11	1.7	0.29	2.5	6.0
3A	0.09	1.3	0.14	2.0	7.0
3B	0.12	2.1	0.14	2.5	6.0
4A	0.05	1.2	0.50	2.5	7.0
4B	0.05	2.7	0.14	2.0	5.0
4C	0.05	2.7	0.14	2.5	6.0

TABLE 13

B. Mud (Concentrations in ppm)

OUTFALL

Stations	Cu	Pb	Zn	Cr	Ni
1B	5	17	28	122	73
1C	5	18	34	62	43
2A	9	17	34	63	43
2B	8	18	38	63	69
2C	8	17	61	64	47
3A	20	33	25	63	76
3B	6	32	17	125	60
4A	15	67	46	312	125
4B	6	33	18	125	60
4C	3	58	39	125	43

6. A SUGGESTED PATTERN OF WATER BODIES WITHIN THE SIERRA LEONE RIVER ESTUARY FROM A STUDY OF TEMPERATURE/SALINITY PROFILES ALONG OUTFALLS UNDER INVESTIGATION.

Layering resulting from the intrusion of oceanic water into the Estuary during ebb tide in the dry season, produces a complex pattern of water bodies which could be easily discerned from their colour. Distinct lines which are glossy or smooth and shiny when viewed from above indicate the areas where these bodies of water meet. These lines are not only marked by debris, detritus, empty tin cans, piassava and used plastics but also by large quantities of untreated sewage. The lines tend to run parallel to the estuarine shore along the long-axis of the estuary. During recent investigations, results of which are shown in Figs 3 and 4, it was apparent that at least three types of water could be present in the estuary at low tide (Fig.5). These diagrams also throw some light on a possible movement of water in the Estuary. The three types of water which could be present in the Estuary at low tide are:-

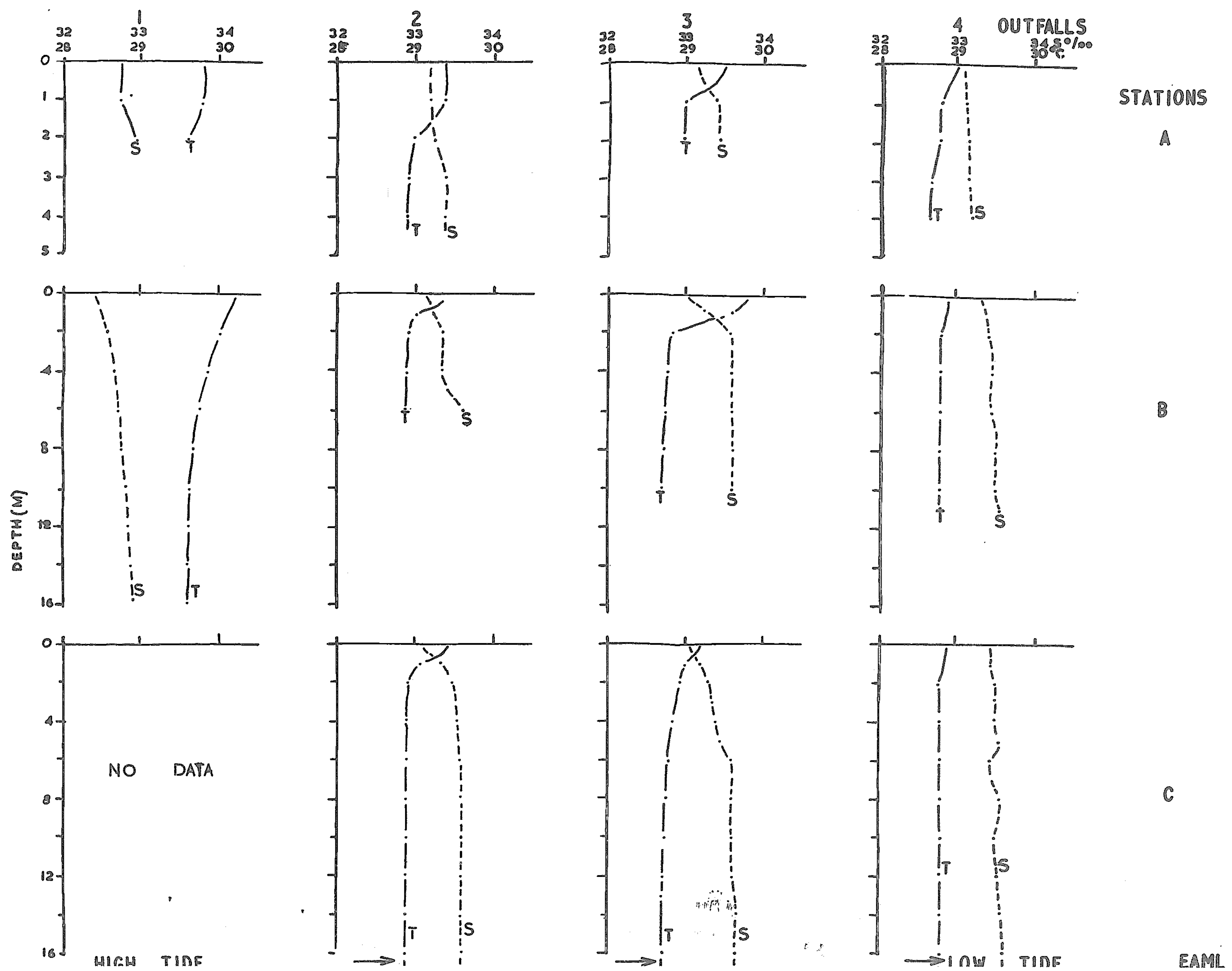
(i) Bay water, which is found in the bays along the Southern shores of the Estuary.

(ii) Estuary water which extends from the bays to about 250m off the mainland and

(iii) Oceanic water which extends from midstream to the Bullom shore.

(1) Bay water - This water which is either brown or yellow in colour appears to be of the poorest quality, being heavily polluted with organ materials - refuse, gabbage, sewage and oil which are being dumped into streams that empty into the bays by the local Freetown population and the Sierra Leone Oil Refinery sited at Kissy. Three species of fouling organisms - *Crassostrea tulipa* (oyster), *Balanus amphitrite* and *Cthamalus stellatus* (barnacles) characterize this body

Fig. 3. Temperature/Salinity profiles at three stations (A - 10m, B - 50m, C - 100m Offshore) at each outfall along the northern shores of the Sierra Leone Peninsula on the 7th of May 1980.

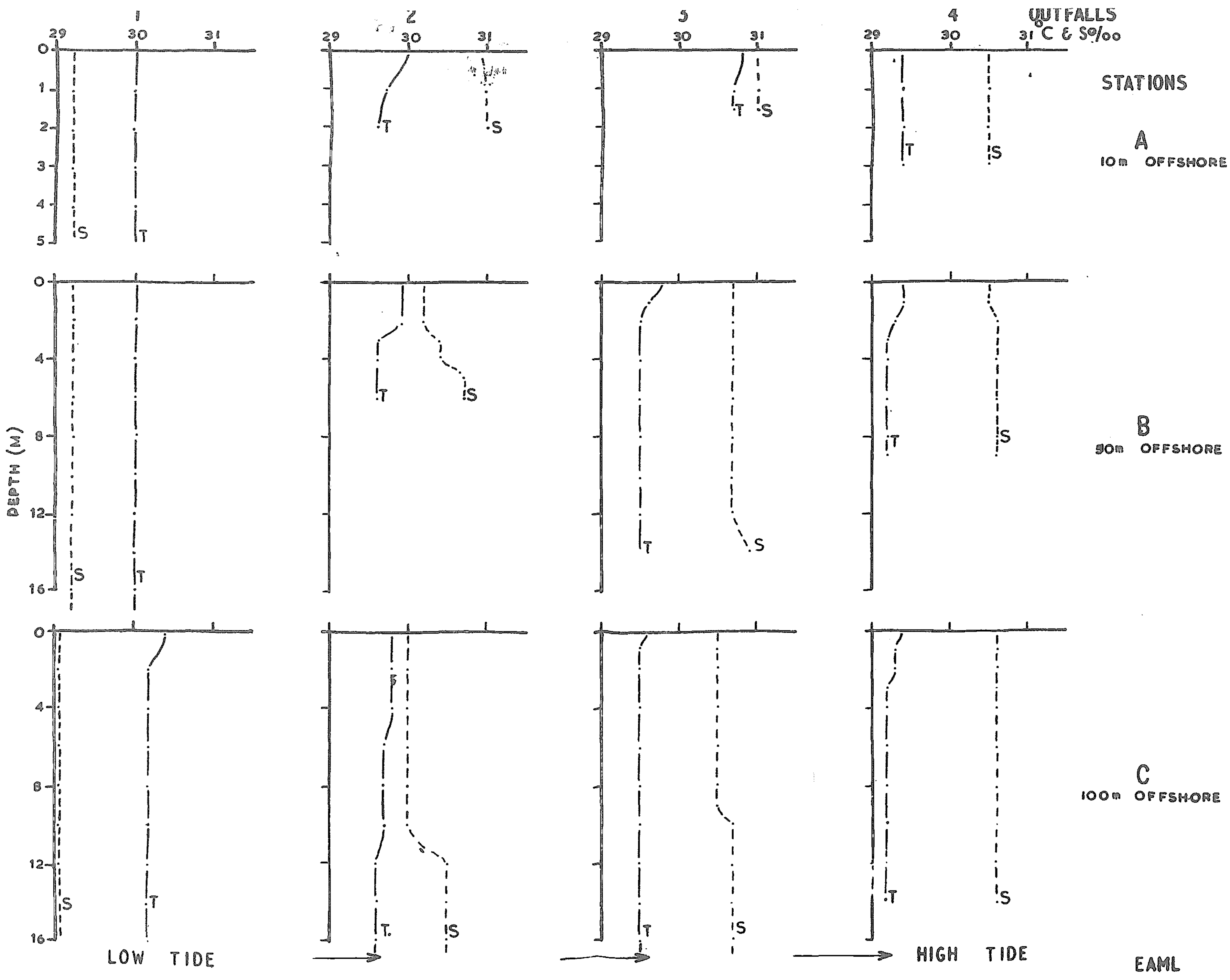

OUTFALLS
1
2
3
4
32
28
33
29
34
30
34 S°/oo
30 °C
STATIONS
A
B
C
DEPTH (M)
0
1
2
3
4
5
8
12
16
T
S
NO DATA
HIGH TIDE
LOW TIDE
EAML

of water. These species are known to settle on piers and steel pipes and in the latter case blocking the sea water intake pipes in the cooling systems of the electricity generators of the Sierra Leone Electricity Corporation at Kingtom. In the dry season, this body of water appears to be more or less permanently locked up in the bays with little or no mixing with the estuary water. These bay waters apparently move upstream when the tide at mid-stream in the Estuary is running out (ebbing). The water is highly mixed probably due to wave action along the shore (Figs 3 and 4). The area occupied by this body of water extends about 5 to 10m outside the mouth of the bays and only about 10m offshore at the headlands. The depth of this body of water ranges from 0m at the shore to about 10m offshore.

(2) The estuary water, which is usually green or light brown in colour lies between the bay waters and the more or less oceanic water at the middle of the Estuary. It is separated from the estuary water by a distinct front-line (which is termed here as the Bay Water Discontinuity) and from the oceanic water offshore by the Estuarine Front-line. This body of water appears to be mostly stratified during the dry season (Figs 3 and 4) although the depth at which the thermocline lies does not exceed 5m. At most, the thermocline is about 2m below the surface. Organic pollution is relatively low although it increases in an upstream direction. Decaying parts of plants form the bulk of suspended matter in this body of water. The water is characterized by typically estuarine species of zooplankton e.g. Temora turbinata and Schmeckeria serricaudatus.

(3) Oceanic water occupies the deep channel and the Middle Ground areas. Patches of this water type could be seen floating within the

Fig. 4. Temperature/Salinity profiles at three stations at each outfall along the northern shores of the Sierra Leone Peninsula on the 13th of May 1980.


OUTFALLS
1
2
3
4
°C & S‰
29
30
31
DEPTH (M)
0
1
2
3
4
5
8
12
16
S
T
STATIONS
A
10m OFFSHORE
B
50m OFFSHORE
C
100m OFFSHORE
LOW TIDE
HIGH TIDE
EAML

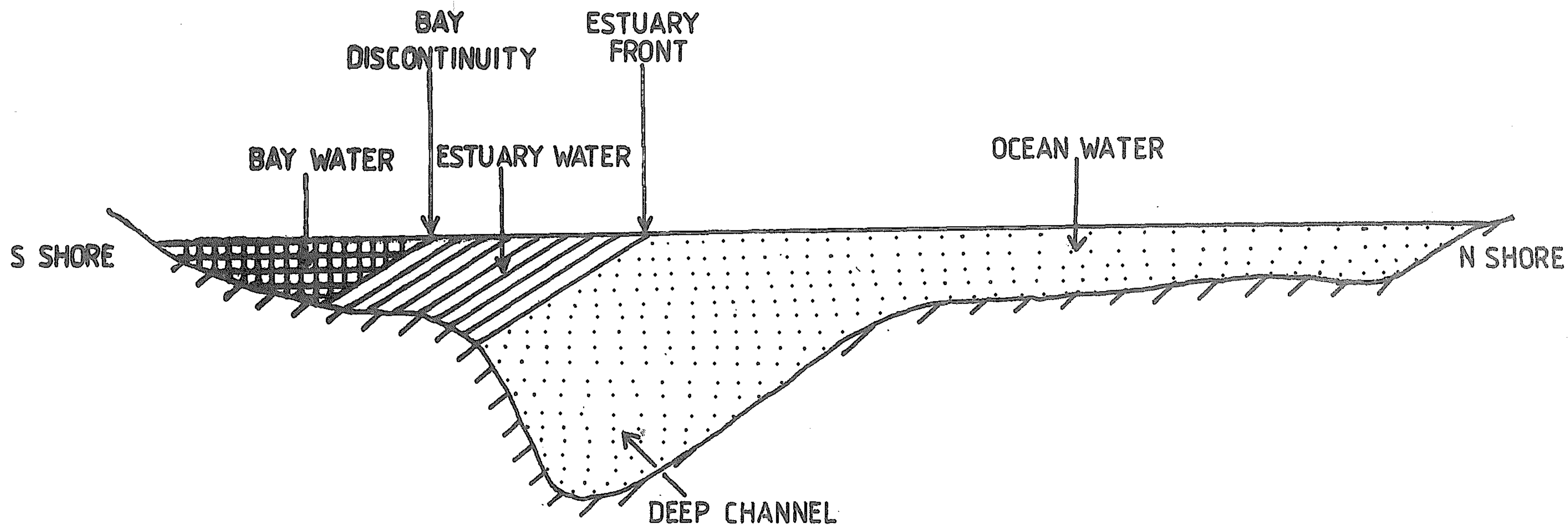


Fig 5 A schematic cross-section of the estuary showing water-types front and discontinuity at low tide

estuary water. Although the formation of these clean, clear, blue/green patches of water in the Estuary is unknown nevertheless it is suggested that knowledge gained from studies on their origin, growth, movements and decay, would throw light on the dissipation of pollutants and the flushing rates of the estuary water. The presence of oceanic water in the Estuary can be noted by the occurrence of *Sagitta enflata* which is a zooplankton species common in the continental shelf of Sierra Leone. The oceanic water invading the Estuary is not stratified probably due to the high current velocities experienced within it.

7. REVIEW ARTICLES OF THE SIERRA LEONE RIVER ESTUARY

7.1 PLANKTON OF THE SIERRA LEONE RIVER ESTUARY

The Sierra Leone River Estuary is located in a geographical region which experiences two clearly defined climatic seasons:- a rainy season which starts in April or May and continues to October or November and a dry season from October/November to April or May. Frequent line squalls in May and again in October herald the beginning and end of the rainy season. Monthly maximum rainfall occurs either in August or September. Sea water temperature drops to a minimum during this season due to increased cloud cover resulting from the invasion of the area by the South West Monsoons or Equatorial Maritime airmass from the Atlantic in the south and west. During this season numerous streams and rivers which drain the northern part of the Freetown Peninsula and the catchment area of the Sierra Leone River, discharge large volumes of fresh water and consequently decreasing the salinity of the estuary water. Thus, the month of minimum salinity (August or September) of the estuary water coincides with the month of maximum rainfall in the area. The velocity of the stream just outside Freetown then becomes much greater than in the dry season, sometimes running at a rate of 5.0 knots on the ebb. Turbidity is greatly increased due to intense mixing of the estuary water by strong winds and the introduction of debris and detritus resulting from increased run off from the land. Zooplankton numbers decline likewise due to the intense flushing of the estuary by freshwater (Leigh, 1973), the dilution effect of which can be felt almost 200 miles outside the Estuary's mouth and over the Sierra Leone continental shelf (Watts, 1958). Instability of the estuary water and reduced light intensity militate against phytoplankton production at this time when in general nutrient concentrations separating different bodies of water, for example, bay waters and estuary water, disappear due to the intense mixing. In general, the whole estuary appears to be completely flushed and cleaned physically during the rainy season.

Stability returns in November after complete mixing of the Estuary water in October by strong winds from line squalls which mark the end of the rainy season. Nutrients stored in the bottom muds are then brought into circulation (Bainbridge, 1960). The stream velocity drops as fresh water discharge decreases. Thus, in the dry season the stream on the flood runs at about 1.0 to 1.5 knots at springs and from 2.0 to 2.5 knots on the ebb. At neaps the stream on the flood runs at about half a knot and on the ebb at about 1.0 knot. Increase solar radiation resulting from reduced cloud cover leads to the direct warming up of the surface waters which coupled up with increasing stability leads to stratification of the estuary water. Phytoplankton production increases as from December followed by an increase in the numbers of zooplankton in January and February. Rapid uptake of nutrients by the phytoplankton reduces the nutrient concentration to only trace levels.

Reduced fresh water discharge facilitates the intrusion of oceanic water into the Estuary at the bottom (Watts, 1958). This condition is more pronounced at neaps than at springs. As a result of this and extreme evaporation of the surface water, salinity gradually increases reaching a maximum in May or June. The intrusion of cold bottom oceanic water into the Estuary and the prevailing Harmattan winds (dust laden) depress water temperatures at a time when the salinity is intermediate between the maximum and minimum for the year. (Leigh 1973) has shown that two of the main factors affecting the abundance and distribution of plankton in the Estuary are salinity and temperature. Thus, lower water temperatures and optimum salinities probably favour the high standing stock of plankton found in the middle reaches of the Estuary in the middle of the dry season.

As the dry season progresses, sea water temperatures increase reaching a second peak in either April or May. This coincides with the retreat of the Harmattan northwards. Plankton production declines as from February probably because of increased water temperatures and salinity. The decrease continues gradually until May or June when increased fresh water flow from the land flushes out the plankton in the Estuary into the sea.

From theforegoing, the pattern of planktom production is such that from the end of the rainy season to the middle of the dry season, a high standing stock of plankton builds up in the region covering the mouth and middle reaches of the Estuary. During this period (October to February), the salinity and temperature of the water in the two areas suggest a penetration of sea water into the Estuary as fresh water discharge decreases. The cladoceran, Penilia avirostris; the copepod, Temora turbinata; and numerous species of phytoplankton, Biddulphia, Coscinodiscus, Rhizosolenia, Thalassiothrix, Tricodesmuim and Thalassiosira, become very abundant. From March to June, the Estuary water becomes more saline, and with a slightly higher temperature, there follows a subsequent drop in plankton production. However, slightly higher numbers of plankton are maintained by addition from members of the benthic community by turbulence caused by squalls at the beginning of the rainy season. With the advent of the rainy season, salinity begins to fall as rainfall and run-off from the catchment area increase. Plankton production declines likewise with a few individuals of typical estuarine species forming the bulk of the plankton.

7.2 THE BENTHIC COMMUNITY OF THE SIERRA LEONE RIVER ESTUARY

The role of the nature of the bottom deposits in determining the distribution of the benthic organisms is of great significance and has in fact been used by Jones (1950) as the basis of his classification of the animal communities in the Atlantic boreal regions. Based on a similar biocoenosis classification Longhurst (1958) has identified the following assemblages of benthic organisms in the Sierra Leone River Estuary:-

1) The Venus community - occuring near the mouth of the Estuary, or in the deep channel as far up as No.1 buoy on shelly-sand and fine lateritic gravel.
2) The Amphioplus sub-community - occuring on muds, shelly-mud and sandy-muds in the mid-estuarine region.
3) The Venus/Amphioplus transition - occurs only in the Estuary where the two communities intergrade in the lower sections

of it. It becomes progressively less common towards Tasso Island, the upper limit of its occurrence.

4) The *Pachymelania* community - occuring on deposits of coarse sand in the upper estuarine region.

5) The Estuarine gravel community - occuring on lateritic gravel in the deep channel of the Sierra Leone River.

The *Venus* Community contains a predominance of poriferans; nemerteans; small crustaceans; pagurid, procellanid and brachyuran crabs; gastropods; suspension feeding lamellibranchs; asteroids; echinoids and ascidians. Similarly, the *Amphioplus* sub-community has a few species of all these groups, and a dominance of gephyreans, thalassinid crustaceans, polychaetes, deposit feeding lamellibranchs and ophiuroids. The composition of the *Venus/Amphioplus* transition is in some groups intermediate between the two main communities, while in others it has characteristics of its own.

The *Pachymelania* community replaces the *Amphioplus* community at the upper reaches of the Estuary and the subsidiary creeks. In this community the filter-feeding gastropod *Pachymelania aurita* is the most dominant. It contains the bulk of the truly estuarine species. The members are found on sands and muddy sands which are common high up the creeks.

The Estuarine gravel community, occurs on the patches of lateritic gravel that are found in the Sierra Leone River where the bottom currents are most intense. The fauna here is specialised, consisting mostly of sedentary, epifaunal organisms. The characteristic species are:- *Astrangia* sp *Actinian* sp, *Thelepus* sp. *Balanus amphitrite*, *Aspidosiphon venatulum* and *Arca imbricata*.

In the Sierra Leone River Estuary there appears to be little overlap between the Amphioplus sub-community and the Pachymelania community which replaces it at the heads of estuaries and creeks. The upper limit of the Amphioplus sub-community lies in the region of the Bunce Island in the main estuarine axis. Above the island the muddy sand deposits are very sparsely populated and the muddy deposits inhabit a fauna clearly related to the Pachymelania community. The seaward limit of the sub-community corresponds to the boundary between the relatively soft estuarine deposits and the hard shelly-sand grouped around the mouth of the Estuary.

The assemblages that may be affected by the discharge of untreated sewage into the Estuary are therefore the Venus and the Amphioplus communities and the Venus/Amphioplus transition. The characteristic species of these communities are listed below.

Venus community

Branchiostoma leonense; Aloidis sulcata, Astropecten sp, Turris carbonarea, Luidia alternata, Modiolus stultorum, Astrangia sp, Oliva accuminata, Rotula orbiculus.

Amphioplus community

Upogebia furcata; Callianassa balssi, Alpheus pontederiae, Acrocnida semisquamata, Amphioplus congensis, Clymene monilis, Pectinaria sourei, Squilla africana, Marginella amygdala, Natica marochiensis, Cerebratulus sp Iphigenia laevigate, Cultellus tenuis, Clibinarius cooki. The clams Tellina angulatus, Talona explanata, Macoma cumana, Arca senilis and Tellina nymphalis are abundant in the intertidal areas.

Venus/Amphioplus transition

There are no species characteristics of these assemblages, however the assemblages in the Estuary consist mainly of an *Amphioplus* sub community with the addition of isolated individuals from the *Venus* community. The members from the *Venus* community are:- *Nassa tritoniformis*; *Olivia* sp. *Pusionella nifat*, *Luidia alternata*, *Astropecten michaelseni*, *Rotula orbiculus* and *Brachiostoma leonense*. *B. leonense* and *Upogebia* sp. occur in their greatest densities than in the *Venus* and *Amphioplus* sub-community respectively. The *Pachymelania* community members are:- *P. aurita*, *Iphigenia truncata*, *Aloidis trigona*, *Neritina glabrata*, *Neritina oweniana*.

COMMERCIALLY IMPORTANT SHRIMPS FOUND IN THE SIERRA LEONE RIVER ESTUARY

Shrimps represent a principal fishery resource of Sierra Leone waters. The shrimp industry of Sierra Leone is based on four species of the family *Penaeidae* namely - *Penaeus duorarum notialis* (the pink shrimp); *Penaeus kerathurus* (the tiger shrimp), *Parapenaeopsis atlantica* and *Parapenaeus longirostris*.

Of these, only *P. duorarum notialis*, *P. atlantica* and *P. kerathurus* are found in the Sierra Leone River Estuary. They occur mostly in the main axis of the Estuary on sandy-mud and muddy-sands; with only *P. atlantica* penetrating into the creeks.

Spawning occurs offshore, and the larvae and postlarvae are normally planktonic in offshore waters. Upon reaching a certain size, they enter the estuarine nursery grounds where they become benthic, congregating in waters generally less than 1m deep (i.e. the shallows). Eventually the rapidly-growing juveniles migrate from the shallows into deeper waters of the estuary before returning to the sea.

Penaeid larvae subsist on yolk granules until the protozoea I stage, when feeding commences (Linder and Cook, 1970; Cook and Linder, 1970) (Costello and Allen, 1970). Linder and Cook (1970) consider shrimp to be selective and particulate feeders. Their observations reveal that shrimp select food items after searching through sand grans with their pereiopods. Williams (1955), however, suggests that any available organic material may be ingested. Although shrimp are able to ingest a wide variety of potential food items, much of the actual material digested is believed to consist of soft parts, because large, hard fragments cannot pass through the straining apparatus of the pyloric stomach (Williams, 1955).

Literature cited:

Cook, H.L. and M.J. Linder 1970 - Synopsis of biological data on the brown shrimp Penaeus aztecus aztecus, Ives, 1891 FAO Fish Rep. 57 1471 - 1497.

Costello, T.J. and D.M. Allen, 1970 - Synopsis of biological data on the pink shrimp Penaeus duorarum duorarum, FAO Fish Rep. 57 14 - 1537.

Williams, A.B. 1955 - A contribution to the life historius of commercial shrimps (Peacidae) in North Carolina, Bul. Mar. Sci., Gulf Caribb. 5 117-146.

OYSTERS

The creeks and bays of the Estuary are bordered by Mangrove trees on the roots of which occur the Mangrove oysters - Crassostrea tulipa. The oysters are active during larval life (10 - 12 days) and become sessile when they settle on the roots of Mangroves and other solid objects for the rest of their life. Oysters are filter-feeders and the discharge of untreated domestic sewage has a threefold effect on them. It covers the bottom with a sludge which smothers the oyster bed; affects the normal functions of molluscs by reducing the oxygen content of the water; and at the same time greatly increases the bacterial content of the water.

Oysters, in common with other water-filtering molluscs, retain and accumulate these bacteria in their bodies.

7.3 THE SIERRA LEONE RIVER ESTUARY FISHERIES

The fishery resources of Sierra Leone are of two kinds - pelagic and demersal. The pelagic fish species live in the surface waters and feed on other fish or plankton, whereas the demersals feed largely on the benthos living on the bottom.

Pelagic fishery

The main pelagic fishes of commercial importance in the Sierra Leone River Estuary are members of the Clupeid family, namely - Ethmalosa fimbriata, Sardinella eba, Sardinella aurita and Ilisha africana. Not much work has been done on the biology and ecology of the latter.

1. The major fishing ground for E. fimbriata is the Estuary where the fish is called by various names according to the size (Watts, 1963). They are awefu, bonga and bonji or cowre bonga, and they refer to the immature, mature and extra large fish respectively. Salzen (1958) has shown that the modal lengths for awefu, bonga and bonji caught in the Estuary are - awefu about 120 to 150 mm, bonga about 280 mm and bonji about 330 to 390 mm. These size classes probably refer to 1st, 2nd and 3rd year classes. Watts (1963) observed that bonga formed the bulk of the catch within the Estuary and bonji in the open sea; the average modal length from the Estuary being 270 mm and outside the Estuary

about 310 to 350 mm.

Salzen (1958), Postel (1950) and Watts (1963) have shown that the *Ethmalosa* fishery in West Africa is to a large extent seasonal, the fish entering the estuarine areas during the dry season and disappearing with the onset of the rains. The *bonga* is euryhaline (tolerant of salinities ranging from 11 to 42%) and is thus able to enter estuarine areas of low salinity. The tagging experiments of Longhurst (1960) suggest that a considerable exchange of individuals or shoals takes place between the Estuary and offshore banks as far north as the border with Guinea. Since Bainbridge (1961) did not find eggs or larvae of *Ethmalosa* in the Estuary he felt that no appreciable spawning takes place in it. He suggested that spawning takes place in the vicinity of the shallow offshore banks and that after metamorphosis the young migrate inshore.

Bainbridge (1957) found that adult *Ethmalosa* are relatively non-selective feeders and that those caught within the Estuary during the dry season are feeding intensively on phytoplankton, thus increasing their fat content (Watts, 1957). Bainbridge (1960) however felt that the aggregation of *Ethmalosa* in the Sierra Leone River during the dry season is probably related to the very high standing crop of diatoms present at that time of the year.

A more detailed study of the feeding habits of *Ethmalosa* in the Lagos Lagoon, Nigeria has been done by *Fagade et al.* (1971). They identified three size groups according to their food namely - 35 to 69mm, 70 to 169mm and 170 + mm.

The food of the 35 to 69 mm size range comprised of zooplankton (mainly copepods) and the large centric diatoms, *Biddulphia* and *Coscinodiscus*. That of the 70 to 169mm size group was found to be largely zooplankton, with the copepod *Acartia* sp. dominating the stomach contents. In the 170mm and above size group diatoms, zooplankton and unidentified organic matter appeared in large quantities. The large centric diatoms, Coscinodiscus and Biddulphia form 19.6% of the stomach contents, the zooplankton, 20.3%, sand grains, 1.4% and unidentified organic matter, 58.6%.

The 170mm and above size group has a slightly different diet from the bonga of the Sierra Leone River Estuary as the centric diatoms formed the major part of their food. It does appear that with increase in size more phutoplankton is taken as food by Ethmalosa.

2. There are two main species of Sardinella in the coastal and inshore waters of Sierra Leone. They are S. aurita and S. eba. S. eba, like the bonga is euryhaline and S. aurita is stenohaline with a salinity tolerance of only 1%.

S. aurita is an offshore species which seems to be restricted to a zone twenty miles from the coast (Longhurst, 1963).

S. eba is most abundant in the shallow coastal waters. Information received from the Fisheries Division, Ministry of Natural Resources indicate that this fish spawns in October outside the Estuary. The spent fish migrate to the Estuary where they develop to a size of 180mm during the dry season. The migration of spent S. eba out of local coastal waters was evident from their absence in commercial landing samples and samples taken at sea by the Sardinella Project vessel during the FAO Pelagic Fisheries Survey in 1970. Juvenile fish measuring 50 to 110mm are usually abundant and distributed throughout the Estuary from October to April. It appears that during the rains the fish migrates out of the Estuary and offshore since few juveniles were found in inshore areas during the rains.

The diet of S. eba is composed mainly of zooplankton (copepods).

The larvae and juveniles of the tunas have been encountered in the Estuary.

Demersal fishery

The biology of the demersal species has been studied by a number of workers including Fager and Longhurst (1968); Longhurst (1957, 1962, 1965 and 1966) and Watts (1959). Like the pelagic, the estuarine fauna is very similar in composition to the ichthyofauna of the coastal waters of Sierra Leone. Two kinds of fauna have been described with respect to the thermocline by Longhurst (1962; 1966): the Sciaenid fauna and the Sparid fauna. This thermocline is absent in the Estuary consequently adult Sparids are absent. The fauna is essentially mixed.

The following are the important demersal species within the Estuary:

Family	
Sciaenidae	*Pseudotolithus elongatus*, *P. senegalensis* *P. brachygnathus*, *P. typhus*
Polynemidae	*Galeoides decadactylus* *Pentanemous quinaruis* *Polydactylus quadrifilis*
Drepanidae	*Drepane africana*
Pomadasydae	*Pomadasys jubelini* *Pomadasys peroteli*
Cynoglossidae	*Cynoglossus senegalensis* *Cynoglossus goreensis*
Aridae (Catfish)	*Arius gambensis* *Arius heudoloti*
Squalidae	*Scoliodon* sp

Pristidae   *Pristis* sp

Dasyatidae   *Dasyatis margarita*

Very little is known about the biology of the demersal species as a group within the Estuary with the exception of a few, such as *Pseudotolithus elongatus*. Watts (1959) reported on some marking experiments on the more common demersal species in the Sierra Leone River Estuary. He found that there was little interchange of the estuarine fish stocks with the stocks on the open shelf.

Generally Sciaenids prefer shallow waters where temperature averages are about 27°C. The distribution of the species is also related to both the bottom characteristic and salinity.

These species like most tropical species are short-lived with an average of between 3 - 5 years. Some of the species are perhaps better suited to estuarine life than the open sea and grow larger. These include the sole (*Cynoglossus senegalensis*, *C. gorensis*) and the catfishes (*Arius* sp). The above named species are strongly euryhaline. The Drepanidae and Polynemidae show limited tolerance to changes in salinity and prefer medium-mud sandy conditions.

Among the Sciaenidae, *P. elongatus* penetrates deeply into the upper reaches of the Estuary off the grounds at Rogbaray and Potko. The stingrary, *Dasyatis margarita* are very common. Within the Estuary most of the demersal species breed during the dry season (September-April).

Longhurst (1957; 1960) has studied the food and feeding habits of demersal fishes in the Sierra Leone River Estuary. He identified three types of feeding habits namely:-

(i) Those that feed on fish (Ichthyophages).

(ii) Those that feed on the active epifauna and fish and

(iii) Those that feed on sedentary epifauna and infauna. The three types closely fit the classification system proposed by Lagler *et al.* (1977) as Predators, Grazers and Suckers. The main predatory species listed by Longhurst are *Pristis* and *Pseudotolithus senegalensis*. To this list could be added *Sphyraena* sp. The minor prey species taken by these Predators are Penaeids, Brachyura, Stomatopoda, Polychaeta and Cephalopoda. The major grazers are *Ariidae*, *Lutjanus* sp. *Pseudotolithus elongatus*, *Pseudotolithus senegalensis* and *Polydactylus quadrifilis*. The prey species are Penaeids, Bachyura, Mysids, and Cumacea, Stomatopoda, Polychaeta Amphipoda, Gastropoda, Lamellibrachia, Cephalopods, Ophuiroidae and Fish. The Polychaeta, Mollusca and Crustacea are most important. The most important prey species are given in the Table I below.

TABLE I MAJOR FOOD ORGANISMS OF GRAZERS

POLYCHAETA	CRUSTACEA
Glymene monolis	*Panopeus africanus*
Pectinaria sourei	*Menippe nodifrons*
Goniada multidentata	*Callianassa balsii*
Nereid sp	*Aquilla africana*
	Amphipoda sp
MOLLUSCA	*Callinectes* sp
Surcula coerula	
Tellina sp	
Donax oweni	
Glycimeris sp	
ECHINODERMATA	
Ophiuroidea sp	
Holothurian sp	

Major Sucker are Dasyatis margarita, Drepane africana, Geleoides decadactylus, Cynoglossus goreensis, Gerres melanopterus, and Pomadasys jubelini. The major prey species are listed in Table II.

TABLE II MAJOR FOOD ORGANISMS OF SUCKERS

POLYCHAETA	CRUSTACEA
Clymene monilis	Squilla africana
Pectinaria sourei	Latiuetus parvalus
Diopatia neapolitanea	Parapenaeopis atlantica
Gylcera convoluta	Polyonyx sp
Terebellid sp	Callianassa balsii
Lumbrinecis impatiens	Alpheus pontederiae
	Porcellana longicornis
	Lyosquilla septenspinosa

Longhurst (1957, 1960) pointed out that there were a high percentage of empty stomachs during the rainy season and that in general the icthyophagous fishes tend to have a higher proportion of empty stomachs. Also there was a general tendency for smaller-sized fishes of the same species to have proportions of empty stomachs. This latter observation may well be due to regurgitation.

Generally the suckers are able to take a wider variety of foods and the harder species such as Mollusca and Echinodermata.

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